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THE MANUFACTURE OF CYCLE AND MOTOR CYCLE CHAINS.

Paper presented to the Institution, Coventry Section, 5th February, 1930, by C. J. Potts, (Associate Member)

THE specialised methods of manufacture for articles such as safety razors, ball bearings, driving chains, etc., are always of much interest, representing as they do the result of continuous and concentrated thought to make an article better in quality and cheaper in cost. In presenting this paper on the manufacture of cycle and motor cycle chains, I wish to mention that it is chiefly one describing the methods employed by the company to which I belong, and may differ very considerably from those of other manufacturers. This does not infer that one maker's methods are better than another's, for there are always several ways of doing a job, and by continuous and persevering thought many of them can be brought to a high mark of efficiency.

A cycle or motor cycle chain consists of the following parts. Outer plates, inner plates, spindles, bushes, rollers, coupling bolt and nut or coupling spindle and spring connector. I propose to deal with the manufacture of these parts in the order given.

The Making of Outer and Inner Plates.

The plates are blanked by multiple tools which may be found interesting from the tool-making point of view when it is mentioned that in the case of cycle chain plates, the shear clearance is only .0005 inch. The accuracy of making and heat treating the cutting tools is such that very little adjustment, due to distortion or mal-alignment, is required after hardening. The chain plates are blanked on presses working at 250 strokes per minute. The presses are fitted with reels for supporting the coiled strip and for winding the used strip back into coils, for purposes of handling, transport and storage. The blanks are then taken to presses for bevelling the edges and piercing the holes. The outer plates are also named at the same time. The blanks are thrown into the hoppers, fed to the bevelling station, and then transferred to the piercing station. In this operation the plates are gauged for size of hole (.001 inch limit), pitch of holes (.0005 inch limit), and position of holes to profile. In the case of plates requiring to be pierced or broached only, the operation is done on similar presses of smaller capacity. The plates are now ready for heat treatment, which will be dealt with later.

The Making of Bushes.

The bushes are made from strip material, which is rolled from round wire on the machine, the material being annealed between successive rollings when necessary. When the material is rolled to the size required, the coils are annealed and put into stock for the press shop's use. The bushes are made on small presses fitted with an automatic feeding attachment. The drum at the rear of the press supports the coiled material, the material then being fed by tension rolls to the shearing, bending and drifting tools. This operation only forms the bushes approximately to the size and shape required. They are then given a swaging or drifting operation on presses. The bushes are thrown into a hopper and fed down tubes to a carrier plate, which transfers them to a position under the press ram. The punches descend and force the bushes through the dies (in the bolster under the carrier plate) to correct the bushes for inside and outside diameter and shape. Both presses described for making the bushes run at 120 strokes per minute. The bushes are now ready for their heat treatment.

The Making of Rollers.

These are made from strip material, being blanked and cupped on double-throw presses, multiple tools being used up to the capacity of the press. The roller cups are then taken to small machines for a planishing operation which, in effect is to form a sharp square edge to the outside bottom face of cup, and to reduce the thickness of metal in the bottom of the cup so that the amount

of sheared surface in the next operation of piercing will be as small as possible. The machines for both planishing and piercing of the rollers are very similar. The output from one battery of machines comprising one blanking, four planishing and four piercing machines is 24,000 cycle chain rollers per hour. The rollers are afterwards ready for heat treatment.

The Making of Spindles.

In the case of cycle chain spindles, the wire material is fed through heading machines where spindles are sheared to length, swaged to size, and centred in each end at the rate of 5,300 per hour. In the case of spindles which have reduced ends, the blanks are sheared off on the machines just described, and then taken to small single stroke heading machines fitted with hopper feed for the swaging of the ends. The spindles are then heat treated and afterwards put into tumbling machines for cleaning, and removing the sharp edge of ends for the purpose of assembling.

The Making of Bolts.

The blanks for bolts are made on heading machines in the same manner as that described for spindles, by fitting dies of a suitable shape for swaging the reduced portion for the screw thread, and for upsetting the head. They are then screwed on the thread rolling machine and afterwards slotted in the head. The bolts are now ready for heat treatment.

The Making of Nuts.

The nuts are made from strip material, being blanked and pierced in one operation in a similar manner to that described for the plates. They are tapped on a small two-spindle machine fitted with hopper feed at the rate of seventy per minute which, incidently, is approximately the same output as the bolt slotting machine, one girl operator attending both machines, and thus equalising the quantity made by this arrangement.

The Making of Coupling Spindles.

These are made on small auto lathes, heat treated, and ground on centreless grinding machines, and do not call for any particular remarks.

The Making of Spring Connectors.

The spring connectors are blanked and pierced in one operation by follow-on tools, afterwards being heat treated.

Heat Treatment.

Every component of a cycle or motor cycle chain is hardened with the exception of the nut, the nut only being coloured. In the case of parts to be hardened, rotary furnaces for the use of gas or solid compound as the case-hardening medium are used.

The furnace consists of a retort six feet long having a scrolled bore, with a conical hopper fitted one end, and discharge chute and quenching tanks arranged at the other end, the retort being heated by gas. A scoop inside the conical hopper collects a quantity of work at each revolution, and drops it into the retort. By means of the scrolled bore of retort, the work is carried along to the discharge end (by which time the required amount of heating and carburising has been received by the work), being then discharged through a hole in the retort and quenched out in the tanks. The tanks consist of a cylindrical member which guides the work into a large wire basket resting on the bottom of the quenching tank. This quenching tank is supported in an outer tank in which water is being continually circulated by pumps for cooling purposes. After hardening, the work is cleaned in simple barrelling machines, the barrels containing water and a small amount of fine abrasive or scouring material. The work is then dried in similar machines in which the barrel is in the form of an inner and outer cup, between which a gas burner is inserted for heating and drying the work. Tempering and colouring of components is carried out in the same manner.

Assembling.

Before the final assembling of the chains the following parts are built up according to requirements :

Outer spindles, which consist of one outer plate and two spindles.

Inner spindles, which consist of one inner plate and two bushes.

Blocks, which consist of two inner plates, two bushes and two rollers.

Connecting spindles, which consist of one outer plate and two coupling spindles.

The assembling of outer and inner spindles is performed on presses. The spindles or bushes are thrown into the hopper above the press, the plates being placed in the column hopper in front of the press ram. By means of spring tension feeders one plate and two spindles or bushes are fed to a station under the punch, and by means of receding pegs in the punch are accurately aligned before being pressed together. The blocks are assembled on machines direct from separate component parts, and give an output of forty blocks per minute. The connecting spindles after assembling have the spindles peened over the plates on the spinning machines. The reason for spinning these spindle ends instead of hammering (as done on the other spindles) being to avoid the risk of damaging the end which carries the spring connector, during manufacture. The outer spindles and blocks are threaded into chains by hand to the lengths required, after which they are taken to presses similar to those used for spindle assembling, for the

assembling of outer plates on the side left without them from the threading operation. A point of interest in the threading operation is the method used for ascertaining the length of half inch pitch cycle chains (the length, of course, varying according to customer's requirements). After threading, the chain is coiled and takes the form of a square-shaped scroll, and a symetrical row of blocks is formed diagonally across the square. By counting the number of blocks along this row from the open hole in the middle block, and adding extra blocks on the outer strand from the corner of the diagonal referred to, the girls can immediately tell the length of chain made. The explanation of this is that the inner coil contains four pitches, and each succeeding outer scroll has an increment of four pitches. Thus a seven-row scroll contains 112 pitches (fifty-six blocks). For chains 118 pitches long (requiring fifty-nine blocks) the assembler would count the seven rows referred to and add three blocks to give the required length. Another point of interest is the knack of handling the chains as coiled on the threading bench. The assemblers grip them in such a way that rarely does one of the fifty to sixty loose spindles in each chain fall out.

With regard to feeding the hoppers on assembling presses with plates, machines for stacking the plates on wires (or spits as they are called) are used. Plates which are bevelled on one side only are stacked by hand. Although it is a very monotonous job, and is avoided whenever possible, it is nevertheless interesting to notice the dexterity with which the girls (usually fourteen to sixteen years of age) perform the operation. A heap of plates are put on the table and the girls select each plate individually, and without discerning the actual movement of their fingers a row of plates is observed growing along the palm of one hand. The operators do not sort the plates by means of the bevel or name as may be supposed, but by a slight difference in the colour of each side of plate, which is a consequence of the metal hardening effect in the bevelling operation. It requires a practised eye to perform this operation without making mistakes. The assembled chains are measured for length and backlash within limits of .0005 inch per pitch. I mention these figures to impress upon you the accuracy obtained in producing an article in such large quantities as those handled by chain manufacturers. The chains are now taken to rivetting machines for the peening over of the spindle ends. Motor cycle chains are given an initial running test under load to ensure as good a bearing for the spindles as possible, and to minimise the need for adjustment of the chains after the first few hundred miles of service. The chains are then tested for strength on the hydraulic testing machine. On this machine sixteen chains are dealt with at the same time, each chain of course receiving an independent pull by means of the compressed springs at the stationary adaptor end and the restricted movement of the beam at the moving adaptor

end. The final gauging is carried out by wrapping the chain round a large master sprocket to check pitch and inside width. The chains are then fitted with the coupling required and sent for greasing, which process consists of immersing the chains in liquefied grease at a constant temperature and density. They are afterwards put into their respective packages for despatch.

With regard to the methods for passing the work through the various departments, the system of patrolling inspectors is used for all machine operations. This to a great extent reduces the area required for the inspection department, with a proportional reduction of transport. The work is carried in rectangular work boats, which boats are transported by means of skeleton-frame hand-trucks The work is measured by means of computing scales.

Samples of every batch of material received into the works are subjected to the usual chemical and physical laboratory tests, and await the chemists approval note before being recorded for shop use.

I would like in conclusion to refer to the fact that the usual cycle chain of five feet length contains 601 components, all of which are heat treated, and yet can be bought from the retail shop for 3s. 3d. I feel sure that you will realise the users are getting their benefit of the plant used to produce them at such a comparatively low price. I am indebted to the directors of the Coventry Chain Co., Ltd., for their consent and support to this lecture, and wish to express my thanks to them.

Discussion.

MR. A. H. LLOYD (CHAIRMAN): I think we must agree, after hearing Mr. Potts, that the methods employed in the manufacture of cycle chains comes to us as rather an eye-opener. The lecturer struck the right note in conclusion when he pointed to the quite exceptional value given to the purchaser of cycle chains, when you consider the number of operations involved in the production of this comparatively simple article. I remember the company's works some twenty-five years ago, when I was taken round by the late Mr. Alick. Hill, and in those days machine operations, as we knew them, were very prominent features in the manufacture of cycle chains. It is a remarkable tribute to production engineers that they have improved continually the method of manufacture, in response to the demands for lower and lower costs of manufacture and selling price, and to-day I think the only machining operations in the manufacture of the chain consist of slotting the bolt and tapping the nut, the others being entirely press operations, and press operations are the most rapid known methods of producing work that we have to-day. Of course, press operations call for extreme accuracy in manufacturing the tools themselves, and multiple punches with half-a-thou' clearance must command the

respect of all people who know anything about tools. One thing I should like to ask the lecturer concerns a matter in which I am particularly interested. I know one chain manufacturer who is using his scrap strip off one process as a means of baling swarf and disposing of it in a very compact form. I should like to know whether you have experimented with this and, if so, whether you have found it practicable, because there might be a possible outlet for excess of your scrap to the people of this district who could use the strip in the baling of their swarf. The rust-preventing operation carried out by dipping in melted vaseline is one of which we have had some experience, and we find that it is a most economical method to bring the work up to the temperature of the liquid vaseline in order to prevent too thick a film being deposited.

Mr. Potts: With regard to making use of strip scrap, I am inclined to the opinion that the baling method is the proper one, but the query against it is the fluctuating price of scrap. I went into the question of baling scrap strip and swarf four or five years ago and found that it was a profitable proposition, using our strip scrap of course for binding. I could not say off-hand whether it is now a profitable one, it is all a question of scrap prices with which I am not in touch. With regard to the methods for preventing rust on work, it is quite evident that the better plan is to remove any sweating or vapouring by bringing the job up to the temperature of the vaseline or lubricant. I do not know that we have had any trouble over that.

Mr. E. W. Hancock: It is of considerable interest to me to know that a production engineer is faced with the apparently simple problem of producing an assembly which has so few pieces and which, within its range of sizes, is virtually the same. Viewed in the light of the normal production engineer's problems, namely, where on one assembly only there can be anything up to two thousand pieces, and with the certainty that many of these pieces will be redesigned within a period of a few weeks, the production of cycle chains would appear to be a very simple matter, as having once settled the problem, it is more a question of tool upkeep, material handling and progressing. Although the title of the paper does not include the manufacture of the so-called "silent chain" I would like to ask, if I am permitted, the method of making the links of this type of chain, especially the angles, as so far as my experience goes, these chains are usually noisy, and there is a never ending argument between the chain makers and wheel makers as to which is correct. Mr. Potts mentioned gauging links, etc., to .0005 inch, and I would like to know how this is done, and with such an enormous number of pieces they produce per minute, I was unable to see how these pieces were gauged to .0005 inch.

Mr. Potts: In the first place we do not make "noiseless chains." They were called by that term until three or four years ago, but

they are "inverted tooth chains" now. Regarding the gauging to half-a-thou' limit. I mentioned that in connection with the pitching of holes. We use hand gauges in which two pins have been mounted (the pins being considerably less in diameter than the size of the holes in the job), the pins impinging upon the outer edges of the hole. With regard to angles. The blocks, after assembling, are ground on machines which consist of a cast iron frame on which two grinding spindles move backwards and forwards, set, of course, to the angle at which the work has to be ground. The block is fed through, located by pegs, and held by pressure plates whilst the grinding wheels sweep off the excess material, giving a ground surface which is accurate to size. The limit on the distance between the centre of the holes and the working face is only one and a half thou' on blocks for chains up to half inch pitch, and this accuracy is maintained. The gauging for angle is done by small hand gauges which consist of a plate fitted with two pegs (on which the work is placed) and a sliding wedge-shaped member. The sliding member is graduated for limits, the graduations being spaced well apart owing to the small amount of taper given to the slide.

MR. AIERS: Referring to the steel containers shown about the shop floors, why don't they put the machines in line and use a conveyor? I imagine that they have automatic weighing machines. For counting, is there not an indicator on each of the presses which would cut that out? Could you not put these on the presses so that you could see from the machine what was going through?

MR. POTTS: Conveyors. We are just going into the matter of conveyors at the moment. One of the difficulties is, of course, the large number of sizes of work going through. You might have a battery of twenty or forty presses all doing the same operation, but there may be ten or twelve different sizes of work going through. Some may be running from week-end to week-end on the same size of job, others may be changed every day. If you have a conveyor system you must make provision for taking the work off and handling it after it comes to the presses from the conveyor. It would be quite simple to put a conveyor down between the presses, and if it can be done in such a way as to meet demands it may come to that. Computing scales and indicators on presses. We do put counters on some of the presses but they are not recommended for payment of wages. Counters on machines are workshop tools for giving workshop executives some idea of the number of parts being done, but as regards using these counters for determining the amount of work upon which wages should be paid would be foolish. You might have registering strokes that only cut air.

MR. TIPPLE: With regard to the testing machines, I should like to know whether Mr. Potts is prepared to say what proportion of the actual breaking load on the chain is allowed, and more parti-

cularly in what way it is done. I remember a few years ago they had trouble on the railways through the draw rods breaking on expresses, and they put in testing machines to determine the load which should be put on them, and that was quite a question at the time. I suppose something of that sort would occur here, and should be glad if the lecturer would state what he considers to be a working load for a chain as distinct from a breaking load. It seems that they have good production methods up to a certain stage beyond which there are special allowances to be made. Do they actually assemble the chains to the particular length ordered, or do they make long lengths first and then divide them as required ?

MR. POTTS : With regard to the testing of cycle and motor cycle chains. The factor of safety for the working load of the chains is anything from twenty-four to twenty-eight, and the testing load is approximately one-third of the breaking load. Thus the test load is about eight times greater than the working load, which is the explanation of the fact that you very seldom have a chain break in service under good conditions. With regard to lengths. We make stock lengths and also lengths to special requirements. The bulk of our orders are in real production quantities, in which case we make the chains to the length required, but when it is a case of dealing with small orders or for stock, we make one standard length (five feet in the case of cycle chains), and shorten or lengthen as required.

MR. NEWBOLD : It would be interesting to know how much cutting clearance they allow in the dies, and what would be the punch clearance for steel one-sixteenth inch thick.

MR. POTTS : The cutting clearance in blanking dies is a quarter of a degree and the total punch clearance for one-sixteenth inch material would be two thou'. Generally, with regard to clearances I don't think you can go very far away from those given in "Machinery." It is always a question of speed and material, but for common use I think clearances given in "Machinery" are very good.

MR. NEWBOLD : In making holes in the stripper sometimes a punch buckles if not hardened to its proper density, and you get a little side pressure. Would allowance be made for this ?

MR. POTTS : I think that question is bound up with that of accuracy in tool-making. If caulking had been done the vibration in service would soon find it out. We do not have any troubles with regard to that, chiefly on account of the fact that the tools go back to the tool room for the replacement of any of the parts.

MR. NEWBOLD : Do you harden the stripper at all ?

MR. POTTS : Yes, of course we do that.

MR. NEWBOLD : Do you have any difficulty in that ?

MR. POTTS : No.

MR. SHAW : Since coming in I have heard the business of chain

making referred to as a birthday, and also as a paradise, which seems to signify that chain makers are on a good thing. Chain making is a thing which calls for admiration, and I should say that the heat treatment, far from being a soft thing, must be very carefully watched, and also that the inspection of material before it is put into progress must be fairly stiff. When I heard Mr. Potts sum up on the retail cost of the chain and the number of components in it, it brought to my mind one question, that is, the inspection costs expressed in personnel, and the outlay on labour charged in producing chains.

MR. POTTS: With regard to the paradise in which we are said to be living I was not aware of it until to-night. With regard to chain making, in terms of production, one of the bug-bears, to my mind, is the number of sizes of chains that are made. If you turn to the catalogue of any chain maker you will find three or four sizes of chains which could be used on the same job. That means that you have a multiplication of work, tools and costings which, of course, absorb production costs. That seems absurd, and it is time someone took the initiative and said that, instead of having say twenty-five sizes of roller chain we have decided to cut these sizes down to say ten. Respecting Mr. Shaw's reference to heat treatment, this is naturally a matter for strict supervision to see that the instructions given are being carried out as the material passes through the furnaces. The various heat treatments are found by research, and it is only a question of the foreman doing his job to give us the results. Very rigid inspection is given to the material before it reaches the shops. Pieces are cut off for both chemical and physical laboratory tests. Test pieces are taken from the outside and inside of coils of strip material, and it has been suggested that pieces should be taken from the middle as well. If there is anything questionable about it the whole coil or consignment is returned. That is the real secret of getting uniform and consistent results. Percentage of costs for inspection. Unfortunately, I am not in possession of these figures.

MR. BLACKIE: I should like to know of what material the punches are made. Also when the presses are working at 250 strokes per minute how do you find out when the dies and punches want grinding? As regards counters and counting. You object to having counters on the machines. Could any system be arranged for buying strip metal in certain specified lengths, so that once you had the length you might know the number of parts you would get from that strip and so save counting? As regards the design of the chain, would it not be possible, instead of making bushes out of tube or bar, to press these from strip metal?

MR. POTTS: With regard to tool steels, we use high speed steel for small multiple press tool punches, and for the rest we use the usual high carbon chrome steel. The grinding of tools. The appear-

ance of the sheared edges of work tells you when your blanking or piercing tools require attention. The grinding is chiefly called for on account of the wear of the punches. As we get the punches down for re-grinding then, to save time, we take a very light cut with the grinding wheel over the top of the die. My objection to counting did not go all the way, because we use counters on some of our presses. Counters, however, are not recommended for wage paying systems, but only for workshop use. With regard to tackling the question from the other angle, just issuing the proper amount of material and expecting a specified number of parts to be produced from it, that is not taking into account the variable amount of scrap that is made, and to have too many parts may cause us much trouble to the workshop system as having not enough. With regard to bushes. There are several ways of making them. They sometimes are cupped and drawn from strip material in the same manner as described for the rollers. You get a good job from a cupped bush, but the operations call for a little more care than those for the roller.

MR. SYKES: I should think the success of chain making is absolutely dependent upon the tool-maker. Mr. Hancock referred to gauging. When talking about sixty per minute I should like to know what the scrap is. Unless the tools following on this operation do the inspection for you, there would appear to be some difficulty in getting them passed without inspection. Instead of having inspection, however, you might have jigs made for the succeeding operations which would operate in such a way that if your component was not correct the job would not go in.

MR. POTTS: A machine when set up is not started until an inspector has passed the first few pieces of work from it. He is a perambulating inspector, and calls upon the job two or three times as it is going through. The machinists also do their own gauging, and by this means we are able to keep the work up to requirements. When the work has passed through it goes to the inspection department on its way to the heat-treatment department, and is there subjected to a percentage test. The costs would, obviously, be enormous if we had a hundred per cent. inspection, which I do not think is necessary. The percentage of scrap. I am not able to answer that question.

THE CHAIRMAN: I think that Mr. Potts has had put to him, one or two questions which are outside the scope of the lecture but he has been quite equal to the emergency.

Mr. Hancock concluded the proceedings by proposing a hearty vote of thanks to the lecturer, who briefly responded.

RECENT DEVELOPMENTS IN ENGINEERING MATERIALS.

Paper presented to the Institution, Birmingham Section, 19th February, 1930, by T. H. Turner, M.Sc., A.R.S.M., F.I.C., M.I.M.M.

IN speaking on the subject of recent developments in engineering materials, it is somewhat difficult to decide what one should include under the heading of "recent." There are obviously many members of the Institution of Production Engineers who are well acquainted with the most recent developments in one or other of the directions which I shall be able to mention here. On the other hand, there must be many, at least among the younger members, who will not be "au fait" with subjects other than those in which they are at present engaged. If one may take "recent" to indicate the last five years, rather than the last few months, there are many developments in metallurgical materials to which your attention should be drawn.

In choosing from the many which might be mentioned, I must be permitted to speak of those matters which have interested me more particularly, and I must ask the forgiveness of the many salesmen at the British Industries Fair at Castle Bromwich, if I omit to mention all the wonderful materials which they would have me bring to your attention. That omission can, however, be easily remedied by yourselves visiting the stands.

I speak as an independent student of the subject, unconnected with any of the producers of the materials to which I make reference. Though it is not, and has never been, my duty to advertise new materials, it has been, for a number of years past, my duty to study and read about them. One or another in this audience may know considerably more than I do regarding the matters which I shall be able to touch upon this evening, and I hope that where that is the case, they will not fail to give the meeting the benefit of their greater practical experience, during the discussion.

Production, engineering and metallurgy now form a trinity in which each is so dependent upon the others that it can never be discussed without reference to the others. It is invidious to give a greater measure of importance to one or other of this trinity. To attempt to claim a longer ancestry or nobler traditions for one or the other, is to propound a new form of the old question as to which came first, the hen or the egg!

If I commence my paper with a reference to production figures, it is therefore because production is as necessary to the metallurgist as metals are to the production engineer. Any planning of engin-

eering production must be based upon the availability of the required materials of construction. Many of these will be alloys in which two or more metals, or non-metals, are so blended as to provide a material which approaches nearer to the requirements of the engineer than any one metal could do. The rule is, however, that metals occur in nature so intermingled with harmful impurities that the metallurgist first extracts them as relatively pure metals. Later, they are refined and alloyed with one another, so as to form the synthetic metallic materials which the engineer uses. One may easily become confused, on scanning a paper, to find how much metal is produced and what it costs, for the precious metals are quoted in fine ounces Troy, some other metals in pounds avoirdupois. Quicksilver is quoted in bottles, and many other metals are quoted in long tons.

Iron and steel are economically by far the most important metals. They are also generally the cheapest metals with which one can realise the designs of the drawing office. They may not prove to be the most economical materials from the user's point of view, but that point may be considered later.

What recent advances have been made in the metallurgy of steel and of cast iron? To speak first of steel. This country has contributed very materially to the advancement of our knowledge as regards large ingots. In certain branches of engineering, notably in the manufacture of electrical generators and armaments, the production of faultless ingots of immense size is desired. A committee of the Iron and Steel Institute has published three valuable reports upon what one may term the normal ingot, as produced by most steel makers. As the result of work of this character, the fluid compression methods which were employed in the past have been almost eliminated, and high quality steels are now cast in most countries in wide-topped, grey cast-iron ingot moulds, above which refractory heads, and sometimes dozzles, are fitted, to maintain the supply of molten metal above the solidifying ingot, and thus ensure the filling of the pipe or cavity which is always present in the centre of the top third of ordinary steel ingots.

Last year, Sir Charles Parsons and Mr. Duncan reported experiments which have been carried out on their behalf by a steel maker, in which the ordinary grey cast-iron ingot mould was replaced by an enormous " chill " as the foundryman would call it, at the bottom of a short, wide, refractory-lined ingot mould, the top of which was provided with oil burners. So that in the operation of this method of casting large ingots, cooling took place only from the bottom of the ingot, and the unidirectional freezing resulted in most of the segregates or non-metallic impurities in the molten steel being pushed to the top, where they could be eliminated. I have recently been in touch with Mr. Duncan, and he tells me that they are quite satisfied that the process will be of value, and up

to the present they have cast about two hundred tons of steel by this method. Difficulties have certainly been met, both in the mould and in manipulation of the ingot, but neither Mr. Service, of Messrs. Beardmore's, where the experiments were carried out, nor Mr. Duncan is satisfied with the way in which the operation has been carried out up to the present, and quite recently a twenty ton ingot was cast and forged successfully into two rotor shafts which were, when I made these notes, being machined. The mechanical tests obtained from these shafts were very good.

One of the Sheffield steel makers is at present building a three-ton mould of this character, for casting ingots of alloy steel, and a well known works in Czecho-Slovakia have also stated that they would like to experiment with the method. So far, the steel makers in this country have displayed a rather lukewarm attitude to this work, partly because they have little money available for experiments at the present time, and partly because the short, stumpy, big ingots can, in some cases, not be forged on presses available in this country, although presses large enough for this operation do exist on the Continent. Sir Charles Parsons' and Mr. Duncan's method of making a large ingot is, therefore, to my mind, a development which electrical generator manufacturers will find useful in the long run.

To turn from large ingots to small ingots, the Junker water-cooled mould, which has been applied successfully to non-ferrous metallurgy, producing very smooth-surfaced strips of cupro-nickel and brass and copper, has been used in some experiments in Germany for the manufacture of steel, although up to the present I have not heard of its application in commerce. The experiments, according to a paper which I translated recently, showed that water-cooled moulds for small steel ingots might have economic advantages, as smoother surfaced ingots with shorter pipes were produced. As for the physical properties of the steel, these were little, if at all, better than those of steel cast in ordinary grey iron ingot moulds.

Before leaving the question of steel ingots, I wish to draw your attention to a most valuable paper by Dr. W. H. Hatfield, given this year to the Institution of Automobile Engineers, in which he makes clear the point that electric furnace steel contains very much fewer slag particles than does ordinary open hearth steel. Thus, for materials subject to alternating stresses, where fatigue failure may start from slag inclusions, electric furnace steel is to be preferred, and judging from my observations in the U.S.A., it will be much more widely used in the future than it has been in the past.

Turning now to the development in the chemical composition of the steels: whereas in the past mild steel has been hardened by carburizing, either in the ordinary case hardening method or in molten cyanide, a process has now been introduced whereby

certain special steels, containing aluminium as an essential constituent and, as a rule, chromium or molybdenum in small quantities, are treated at a low temperature for a long time in an atmosphere derived from ammonia gas, which increases the nitrogen content of the case. As judged by hardness measurements and metallographic investigation, the nitrogen hardened steels, known in this country as "Nitralloy" have a thinner but much harder case than have ordinary carburized and case-hardened articles. Furthermore, as it is not necessary to heat articles much above a dull red heat, the distortion which is produced in quenching, from a high temperature, ordinary carburized steel, does not occur with nitrogen hardening. In addition, this material possesses very considerable resistance to corrosion, and is being used in some cases for pump parts, in which the wear is generally more due to corrosion than abrasion. Nitrogen-hardened steels have been employed in first class French aero engines, and in some American automobile work, but so far they have not proved capable of replacing the better known alloy steels, partly on account of the greater first cost of these new steels—a matter which may in time rectify itself—and partly on account of the unusually prolonged heat treatment operation.

As regards the more ordinary alloy steels, it may be mentioned that three and five per cent. nickel steel has become more popular, on account of its ability to produce a good case-hardened article with only one quench. As most of you are aware, it is generally necessary to heat a case-hardened article two, or even three times, in order to produce the best results. Every operation costs money, and therefore it may pay to use a somewhat more expensive steel, if by so doing it is possible to eliminate one or more heat treatment operations. In this connection, it is also worth mentioning that the use of high temperature quenching baths offers distinct advantages, and is being introduced in certain directions. By quenching a steel in a molten salt at between 200° and 250° C., one may combine the quenching operation with the tempering operation, and have the added advantage that the great strain of completely cooling in a very short time is not necessitated. In other words, one very much decreases the liability of cracking during heat treatment. It is possible to show, by means of a curve, that approximately the same results are obtained by quenching in a molten salt as by quenching right out and tempering.

Still another development in this connection will be of interest to production engineers, and that is some work by an Englishman named Dartry Lewis, now in America. He showed, at one of the Iron and Steel Institute meetings last year, that an ordinary high carbon steel, quenched in a heated molten salt in this manner, remained in the austenitic condition for some few seconds after it was withdrawn from the molten salt. The austenitic condition

is one in which a steel is relatively ductile as, for instance, in "Staybrite" steel, which is extremely tough and by no means brittle. The martensitic state is one in which a steel is very hard and brittle, as in a water-quenched high carbon steel tool. Dartry Lewis has shown that the steel quenched in the molten salt does not change from the austenitic condition into the martensitic condition immediately, and it is therefore possible to quench a piece of steel in molten salt, withdraw it from the molten salt, and work it in any desired manner for two or three seconds and then, of its own accord, it will turn into the hard, martensitic condition. This phenomenon may obviously be of value to production engineers.

The ability to work a material in a soft condition, and then to have it harden up without being deformed by a high temperature treatment, is frequently desired, and the well known austenitic high-nickel, high-chromium steels can be made to do this by the addition of small quantities of the relatively rare element beryllium. With duralumin, the well known strong alloy of aluminium, we are accustomed to heat the metal in a salt bath and to leave it to "age harden." Some newer aluminium alloys do not age harden on their own account, as does duralumin, but require a low temperature heat treatment, or accelerated ageing to produce the same phenomenon. The beryllium alloys of iron, containing nickel, work in exactly the same manner, and it is now possible to obtain an iron rich alloy, comparable to "Staybrite" or "Invar," which can be worked in the soft condition and then hardened up to about 600 Brinell, by a low temperature, accelerated ageing process. Up to the present, this is not practised commercially in this country.

Great advances have been made in corrosion resisting and heat resisting steels, the former being mainly stainless irons or stainless steels, which contain approximately thirteen per cent. of chromium and not more than one per cent. of nickel, and austenitic stainless steels of the "Staybrite" and "Anka" types, the latter possessing the greatest resistance to corrosion. In this connection, you may be interested in the fact that, nearly two years ago, I ordered a bicycle with "Staybrite" steel mudguards and rims. Unfortunately, at that time it was impossible to provide rims of this material, but examination of the bicycle now shows that the unvarnished, unpainted, unprotected "Staybrite" steel mudguards are as good as new, whereas almost every other bright part of the bicycle is red with rust or coated with green or white corrosion products. Steels of this type, with the addition of about four per cent. of tungsten and between one and two per cent. of silicon, have proved most effective as heat resisting materials, and they have been used in the exhaust valves of almost all the leading types of aircraft engines recently produced. Ford is now replacing chromium plating with austenitic nickel-chromium steels.

These austenitic nickel-chromium steels represent a tremendous

advance in the fight against corrosion, and it should be stated that production engineers have fought shy of them unnecessarily on account of the fact that they are difficult to machine. The manager of a foundry which has been very successful in the casting of these steels during the last year or so, maintains that with the correct shape of tool and choice of lubricant, it is possible to machine them at the same speed and with the same feed as ordinary mild steel.

Before leaving the subject of steels, and while mentioning castings, I should like to mention steel castings of a type used on the railways in Canada, U.S.A., and Australia. These enormously long and heavy complicated castings are the underframes of locomotives, and in the latest design, the two side members, cross members and cylinders are all cast together in one single monoblock, a foundry triumph which British steel foundrymen have not been called upon to equal, because locomotive frames are built up from plates in this country, but one cannot help thinking that the existence of castings of that character should be brought to the notice of production engineers as an indication of what can be done.

I turn now to consider the recent advances in the metallurgy of cast iron. From the point of view of availability, cast iron and steel rank as almost equal. On the score of cost, cast iron is frequently cheaper and more suited to manufacturing processes. It suffers from the bad habit of developing hard spots in unexpected places, which break tools. The hard spots in cast iron may possibly be cut through by some of the new tool materials, in which case the machinability may be of less importance than formerly, but in service the hard spots will wear differently from the soft spots, and so it is still desirable that a cast iron article should be uniform in hardness across its section.

Until recently, this was virtually an impossibility, but from 1916 onwards, the Germans developed methods of pre-heating moulds and carefully controlling the composition of the cast iron, with the result that it is now possible to obtain a pearlitic structure across large sections. The Americans, on the other hand, have developed the use of nickel additions, sometimes in conjunction with chromium, to effect the same result, and both have been remarkably successful. As a general classification, one may say that for large articles the Perlit process has obvious possibilities, and that it is not so applicable to small articles, whereas the addition of nickel to cast iron is now standard practice in the manufacture of air-cooled cylinders for the famous Franklin car in America and the American edition of the Cirrus and Gipsy aero engines, to mention but a few of the firms whose names are known on this side. As a matter of fact, more nickel cast iron is now made actually in America than nickel cast steel. This development has also been introduced into Great Britain during the last few years, with the aid of the

B.C.I.R.A., and one of my former students has become a real authority on the subject, and has contributed several papers to the foundry industry upon it. To my mind, there is no reason why alloy steels should not be exactly paralleled by alloy cast irons, and I foresee the continued use of nickel and chromium additions to cast iron for many high duty purposes. Some of these new alloy cast irons have strengths between twenty and forty-five tons per square inch, a truly remarkable figure when one bears in mind that the normal strength of cast iron thirty years or so ago was about four and a half tons per square inch. The addition of nickel to cast iron makes it possible to obtain an almost entirely uniform hardness across very thick sections, and thus makes it possible to have uniform machinability and good wearing properties of castings of irregular shapes. Dr. Everest has told me that in this country a number of manufacturers are using the nickel or nickel-chromium cast irons for dies and die blocks of one form or another, and that these are giving exceptionally good service. I am especially pleased to have heard this, because when I returned from America some years ago and told foundrymen in this country that I had seen nickel being added in many foundries in the States, they were incapable of reproducing the same good results, because they were ignorant of the fact that the addition of nickel must, generally speaking, be coupled with a reduction in the silicon content. Before an engineering audience, I must restrain myself from going into metallurgical explanations, and content myself with saying that these new cast irons can be made with properties superior to those of any cast irons which had previously been manufactured.

A corrosion resistant cast iron has not yet been developed, but austenitic cast irons with approximately sixteen per cent. of nickel and four per cent. of chromium have been introduced successfully under certain conditions, and with further additions of chromium this type of nickel-copper-chromium austenitic cast iron is now perhaps one of the best heat resisting cast irons available.

Before leaving the subject of cast iron, reference should be made to two other developments. On the one hand, we have followed to a large extent American practice in malleable cast iron, in that some of the largest producers of malleable cast iron in this country have turned over to the black heart process, although many of the smaller producers still operate the traditional European, or Reamur, white heart process. As you know, black heart malleable possesses superior physical properties.

Lastly, this country has been in the position of a pioneer as regards the introduction of centrifugal casting, and very great strides have been made in this connection. At Stanton, long pipes suitable for water supply and other such purposes are cast in what is said to be the largest pipe foundry in Europe, and elsewhere

shorter length castings of plain and more complicated shapes are being made. I have had the pleasure of visiting the works at Stanton and Thorncliffe, and have been in communication with Mr. J. E. Hirst, after his recent appointment as technical director to the new Sheepbridge Stokes Centrifugal Castings Co., Ltd.

You are all familiar, I take it, with the application of centrifugal casting to the manufacture of piston rings. Mr. Hirst thinks that one of the outstanding advantages of centrifugal castings for this purpose is the fact that the material is more truly elastic than the ordinary cast iron, and has a more uniform and higher modulus of elasticity. The most recent developments in the application of centrifugal castings is the production of both " wet " and " dry " cylinder liners for internal combustion engines. " Dry " liners, particularly, have been adopted extensively by the motor trade, and so far as experience goes up to date, the life of such liners is at least two to two and a half times that of the original cylinder block. In the heavier industries, the spun sorbitic cast iron developments have been extensively adopted, and a large number of piston valve liners for locomotives, annular rings for metallic packings, and similar items, are being made from this material. It should be realised that centrifugal casting throws the best of the metal to the outside, and that the resultant product is, generally speaking, more fitted for wear on the outside than on the inside. A piston ring body is, to my mind, a more ideal application of this process than is a cylinder liner, but the latter also proved successful and many thousands of castings of this type are now being made every week.

Some of the more irregular shaped castings are worth mentioning. For instance, it is possible to make a Diesel engine cylinder liner by this process, with the holes for ports cast in. That is a development which I first noted in Watertown Arsenal, in the U.S.A., where I also saw the experimental centrifugal casting of steel, white metal and brass.

To return to centrifugally cast iron. This is now made for brake drum liners, gear wheel blanks, solid flywheels, bushes, turbine gland rings, pump barrels, sleeves, and other such parts, and it may have a tensile strength of between nineteen and twenty-two tons per square inch, with Brinell hardness of 200 to 240. I do not know whether centrifugal casting should be regarded as a recent development, since experimental centrifugal casting was made in Mansfield in 1916, but since that date there has been a continuous and successful development, until at present all the better known makes of car, including the London omnibuses, are fitted with centrifugally cast piston rings.

Recently, an entirely new plant has been erected, based on the experience gained at Mansfield, and the new shops are equipped not only for cast iron, but also for steel, non-ferrous metals, and

experimental work. As compared with sand cast material, there can be no doubt that the centrifugal castings possess a finer crystalline structure and a more uniform distribution of the graphite, iron phosphide and other constituents, which materially effect the strength of the resultant product.

The mention of non-ferrous castings by means of the centrifugal process, leads me to speak of other methods of casting non-ferrous materials, which are of increasing importance to the production engineer. Shortly after the war, we heard that the German manufacturers were making tremendous developments in die-casting, and gradually the die-casting industry in this country has grown until, at the present time, one can obtain die-castings in many different alloys of various strengths and corrosion resistances. I am indebted to Mr. Mundey, of Fry's Metal Foundries, Ltd., one of the leading British producers, for the samples of die castings which are here exhibited. In every case he has, at my request, put on the article the cost of the die and the price of the article, in lots of five hundred to a hundred thousand, as the case may be.

One can scarcely claim that white brass is a recent development, but in its present form it is a vastly more reliable material than formerly. White brass is the trade name for what the metallurgist terms a "zinc-base die-casting alloy" and that will be mainly zinc, with aluminium and copper added as a hardener. White brass will have a tensile strength of between twelve and fourteen tons per square inch. Aluminium die castings are made in a number of different alloys, one of the most popular being an aluminium silicon alloy. This has a strength of about twelve tons per square inch. The last category, yellow brass, is undoubtedly a recent development in this country, although in 1926 I saw the outside of a factory which was alleged to be producing yellow brass die castings at Batavia, near the Great Lakes in the U.S.A. Fry's Metal Foundries have recently obtained some new types of die casting machinery, and the five samples which I here show have been made by this new process. They are remarkably interesting, having very much sharper details than could be produced in sand casting of this alloy. Moreover, their tensile strength is about twenty-eight to thirty-two tons per square inch.

Many other small parts are similarly die cast from tin base alloys, and it is difficult to give the price of these, owing to great fluctuation in the price of their principal constituent, and they must therefore be quoted separately and specially in all instances. These four groups probably represent the alloys normally made as pressure die-castings. Aluminium bronze is produced by the same concern, and by an increasing number of foundries, in the form of gravity die-castings, and these are of great interest where strength and resistance to corrosion are essential. I may mention here that,

from my own observation, I think that Great Britain is ahead of other countries as regards the gravity die casting of large aluminium alloy articles, such as crankcases, but that other countries have led us in the development of die-casting machines of the pressure type. Finally, mention should be made of the fact that magnesium alloys are now made as die-castings, with a great facility. I have here two gear box covers made from the same die by the Birmingham Aluminium Casting Company. They should not be regarded as in any way standard products, as they were kindly handed to a colleague of mine some months ago when a party of our students visited that works, and at that time the new method was in its experimental stage. However, you will see that the magnesium alloy has been cast without apparent trouble, to exactly the same dimensions as a normal aluminium alloy, and it can be easily demonstrated by balancing the one against the other, that the new magnesium alloy is approximately thirty to forty per cent. lighter than the aluminium alloy. Mr. Player, of Sterling Metals, Ltd., Coventry, who has fathered the development of magnesium alloys in this country, says that they are to be preferred to aluminium for die casting work, as magnesium does not attack the dies in the way that aluminium and other metals do.

This mention of the new magnesium alloys leads me on to other recent light alloys. The composition of RR.50 may be regarded as that of the well known " Y " alloy with about half a per cent. of the nickel replaced by titanium, and the addition of an appreciable amount of silicon. This alloy is regarded as the greatest advance that has been made as regards a material for chill cast pistons. It is particularly easily cast, and is not only being used by the Rolls Royce company but also in increasingly large quantities by the whole of the aircraft industry. In passing, it is worth mentioning that this alloy was used for the crankcase, cylinder block, and cylinder head, and other aluminium castings in the famous engine installed in the winning plane of the 1929 Schneider Trophy race. Mr. Devereux regards this alloy as the most easily cast aluminium material that he has handled, and the most valuable in service, and says that it will do much to ease the work of the modern foundry and light alloy forge, and he is as well fitted to judge as anyone in the country, having established a foundry which, in a matter of two or three years, has grown from nothing to being the second largest user of aluminium in this country and to supplying the new materials he handles to the aero engine and motor car industries in this country, and also exporting it to France, Germany and America. His foundry is entirely controlled by laboratory methods and deserves mention in any lecture dealing with recent developments in engineering materials, for it is one of the outstanding proofs that laboratory methods provide the most successful means for getting the best production.

Both the Rolls Royce alloy and " Y " alloy are improved by heat treatment, the temperature differing slightly. The forging and stamping of " Y " alloy should be carried out at from 480° to 500° C., and may be continued down to about 350° C. The forging of duralumin should similarly be carried out from 450° to 480° C. For the new RR.50 alloy, it is safe to go as high as 520° C. In the heat treatment of duralumin, it is soaked at 480° C., quenched in water, and requires between a week and a fortnight to " age harden " before it is put into service. " Y " alloy is heated to 520° C. and " ageing " may be accelerated by heating to 220° C. The RR.50 alloy is soaked between 520° and 540° C. and quenched in water, and then artificially " aged " at 175° C. for something under a day, and finally quenched in water or air, according to the hardness required. Incipient fusion takes place in duralumin at 540° C., in " Y " alloy at 560° C., and in RR.50 at 580° C. Thus, the new alloy has a much greater working range and heat-treatment range than have the older alloys of which it may be regarded as a development.

The further use of aluminium leads me to speak of the work of the British Non-Ferrous Metals Research Association. This Association has done very fine work in the development of the co-operative spirit among British metal manufacturers, and they have exhibited considerable interest in the development of the process of anodic protection for duralumin, and in researches on atmospheric corrosion. In the laboratories of the University of Birmingham, the British Non-Ferrous Metals Research Association workers have, during the last few years, been carrying out experiments on a new aluminium brass, which deserves mention.

Note on a New Aluminium-Brass Condenser Tube.

Origin and Development.

Arising out of some researches carried out for the Association at the Research Department, Woolwich, during the past three to four years, a thorough study has been made of the mechanical and other properties of brass containing special additions of aluminium. The exceptional behaviour of some of these alloys when exposed to corrosive conditions led to their manufacture and trial in the form of condenser tubes.

In co-operation with Mr. R. S. May and Professor H. C. H. Carpenter, tests were carried out in comparison with 70/30 brass tubes. One test consisted of maintaining the tubes over a period of nine months in an experimental condenser, using sea water flowing at a speed of seven feet per second under conditions of high aeration and considerable air impingement.

The examination of the tubes after this test showed startling results. Whereas the ordinary brass tubes were considerably corroded over their whole surface, exhibiting a green colour and, at

the inlet end, a considerable amount of thinning down due to erosion, the new aluminium-brass tube showed no appreciable impingement attack and had a yellow surface with almost the appearance of an enamelled or laquered finish of the original brass.

Further tests have shown that this remarkable result is due to the formation of a film or coating of a highly protective nature. Of still greater importance, and probably of quite an exceptional character, is the automatic reforming of this protective film should it become broken or worn by accidental means. Experiments have clearly shown that the film if deliberately abraded quickly heals up when the rubbing tool is removed, and the metal left freely exposed to aerated sea water. This "self healing" of the film and its highly protective nature are the outstanding features of the new alloy and are actually due to its composition, and in particular to the aluminium content, which is purposely provided.

Composition and Properties.

The composition which appeared desirable as a result of the Woolwich researches on a large number of alloys is seventy-six per cent. copper, twenty-two per cent. zinc, two per cent. aluminium, and this specification was adopted by the British Admiralty in a trial order. It is believed that this composition can be varied within reasonable limits without affecting the self-healing properties of the corrosion-protective film formed under the normal working conditions in a condenser. Fortunately, the increased resistance to corrosion is not gained at the expense of the mechanical strength, workability, or machinability of the material.

The addition of aluminium to the high copper brasses has been found, as a result of these researches, to give alloys of even higher ductility than those without aluminium. The hardness and tensile strength are slightly increased, but the higher elongations undoubtedly facilitate manufacture. Moreover, these aluminium brasses can be worked hot, which also facilitates manufacture, by extrusion, or by hot piercing methods of production.

Thorough tests have been carried out on the tendency to season cracking of these aluminium brasses, and it has been proved that they are certainly no more susceptible to this trouble than the highest grade brasses containing no aluminium, and they can consequently be used without any anxiety in this connection.

The presence of aluminium renders necessary some modification in the early stages of manufacture. With this material it is difficult to obtain sound billets by the ordinary method of pouring, but by the use of the Durville process of casting, which has been acquired by the Association, perfectly sound billets can be assured. This process utilises a combined ladle and mould, and transfers the molten metal (after a short period of quiescence for the separation of any occluded gases, dross, etc.) to the mould, without any break-

ing of the stream of metal, such as necessarily occurs when metal is poured from a crucible. The risk of entrapping oxide or dross is thus entirely obviated, and a perfectly sound billet free from internal discontinuities and hidden flaws is assured.

The subsequent working of the material presents no difficulties, in fact owing to its suitability for hot-working, tube production is greatly facilitated. With due precautions in casting, etc., the resulting tubes pass most stringent inspection and other tests, e.g., the tubes made to satisfy the recent Admiralty order passed the required tests in a most gratifying way and showed splendid finish. The cost of the aluminium-brass is only slightly greater than that of 70/30 brass, an important consideration compared with some of the other alloys now being used for condenser tubes.

The discovery and the availability of such tubes only dates from the last few months, and the results of long service trials are therefore not available, but are awaited with some degree of confidence. It is particularly desirable that users who are concerned in looking for the best materials should arrange for proper service trials, and it is hoped that orders for this material will be placed with the condenser tube manufacturers, most of whom are members of this Association, and should be in a position to supply any requirements called for.

New Views of Corrosion Resistance.

Until the last few years engineers have been looking for materials of an incorrodible nature, hoping that some day a metal would be found which would not be attacked or dissolved under the particular conditions of service in view. Modern research on corrosion has, however, given us quite a new outlook. It is now pretty generally understood that strictly incorrodible metals are beyond the hope of scientific or economic achievement, and that those materials which most nearly approach incorrodibility owe their superior behaviour to the protective nature of the coating or film formed by the early stages of corrosion upon the surface. In other words, instead of looking for a non-corroding metal we now look rather for one which corrodes so fast, but so well, that the resulting oxide or other chemical product forms and maintains an unbroken and tenacious film on the surface.

Considering such problems in this modern way, we may also bear in mind independent research which is being carried out on the oxidation products of a wide range of metals and which points to the exceptional nature of the aluminium oxide coatings. Most oxide coatings are discontinuous and brittle, and therefore either unprotective or even enhacing attack, whereas aluminium oxide, if formed under certain conditions, is strongly adherent, continuous, and highly protective. The practical results of tests with this

tube are promising, and the scientific basis for its properties is well established.

However, the aluminium-brass tube is a possibility of the future. The great development in this direction in recent years has been the introduction of cupro-nickel condenser tubes into almost all first class craft and land stations.

Another outstanding example of British Non-Ferrous Metals Research Association work is in the development of superior types of lead, which can be used for most of the purposes for which pure lead has normally been employed up to the present time. As a result of trouble experienced by electric cable manufacturers, with the fracture of the lead sheathing, it was found that the cracking invariably started from the inside and was due to a form of vibration. It was clearly demonstrated that the failure was due to fatigue of the lead. The remedy proved to be the substitution of alloys containing alloys of lead, with one or two other elements. The ternary alloys of lead, cadmium and aluminium, and of lead, cadmium and tin, suggest very strongly that advantages are to be gained from their application to pipe for domestic service, roofing sheet, window casements, and other similar purposes. Although the alloying elements slightly increase the price per ton of this metal, its improved mechanical properties actually permit a saving in weight, which results in an overall reduction in the cost of the installation, and this advantage in cost may amount to more than £5 per ton of the equivalent lead, irrespective of the technical advantages which I have already mentioned. This very pretty piece of research, of undoubted wide application in the industries of this country, cost approximately £5,000, which sum was mainly contributed by the cable manufacturers. It is to be hoped that, as the British Non-Ferrous Metals Research Association is not a money-making concern, any others who benefit by the research will either become members of that Association or in some way contribute to it. The success of this piece of research has already been recognised, in that the G.P.O. has applied these alloys to two submarine cables which consumed upwards of seven hundred tons, while the Admiralty, after thorough trials, has specified a ternary alloy to be used for the sheathings of all cables installed in His Majesty's ships, so that by now, several thousand tons of the material have been successfully made and installed.

One of the developments about which I might have spoken at considerable length, is the production of tungsten carbide alloys, these being introduced originally by Krupp's, of Essen, Widia, and later by the General Electric, of Schenactady, as "Carboloy." These extremely hard and brittle tungsten carbide cutting alloys will probably be of great value to production engineers, but your syllabus for this year promises a discussion on cutting tools, in March, and so I refrain from dealing with the subject to-night.

In conclusion I propose to commit the metallurgical consultant's form of Hari Kari in pointing out to you, as forcibly as I can, that sharp corners are fatal. My experience in the works and as a consultant has taught me that a mechanism made from cheap steel but designed with no sharp corners, is more likely to avoid the scrap heap than one made with sharp corners and of the best material purchasable.